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EXPLORING THE IMPACT OF GREEN ENVIRONMENT ON ECONOMIC GROWTH: THE ROLE OF FINANCIAL DEVELOPMENT - A BAYESIAN QUANTILE REGRESSION APPROACH

EXPLORANDO O IMPACTO DO MEIO AMBIENTE VERDE NO CRESCIMENTO ECONÔMICO: O PAPEL DO DESENVOLVIMENTO FINANCEIRO - UMA ABORDAGEM DE REGRESSÃO QUANTIL BAYESIANA

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Abstract
Despite environmental concerns, we believe that the benefits outweigh the costs. This study examines the actual impact of the green environment (GE) on economic growth (GDP) and investigates the moderating role of financial development (FD) across 65 countries worldwide over the period 2004 to 2020. Using the Bayesian quantile regression approach, the study evaluates the effect of the green environment across different distributions of economic growth and explores the moderating role of FD. The results show that the green environment has a strong and positive effect on GDP across all quantiles. This finding confirms the important role of the green environment in promoting national economic growth. Notably, FD has a positive relationship with GDP, and when considered in the relationship between GE and GDP, FD amplifies this relationship. These findings highlight the influence of the green environment and the important role of financial development, suggesting that countries should optimize the benefits of GE to promote sustainable economic growth. In addition, policies aimed at improving the financial system are needed to strengthen the impact of GE on GDP.

Keywords: Green Environment. Economic Growth. Financial Development. Bayesian Quantile Regression.

Resumo
Apesar das preocupações ambientais, acreditamos que os benefícios superam os custos. Este estudo examina o impacto real do ambiente verde (AV) no crescimento econômico (PIB) e investiga o papel moderador do desenvolvimento financeiro (DF) em 65 países ao redor do mundo, no período de 2004 a 2020. Utilizando a abordagem de regressão quantílica Bayesiana, o estudo avalia o efeito do ambiente verde em diferentes distribuições de crescimento econômico e explora o papel moderador do DF. Os resultados mostram que o ambiente verde tem um efeito forte e positivo sobre o PIB em todos os quantis. Essa descoberta confirma o importante papel do ambiente verde na promoção do crescimento econômico nacional. Notavelmente, o DF tem uma relação positiva com o PIB e, quando considerado na relação entre AV e PIB, o DF amplifica essa relação. Essas descobertas destacam a influência do ambiente verde e o importante papel do desenvolvimento financeiro, sugerindo que os países devem otimizar os benefícios do AV para promover o crescimento econômico sustentável. Além disso, políticas voltadas para a melhoria do sistema financeiro são necessárias para fortalecer o impacto do AV sobre o PIB.

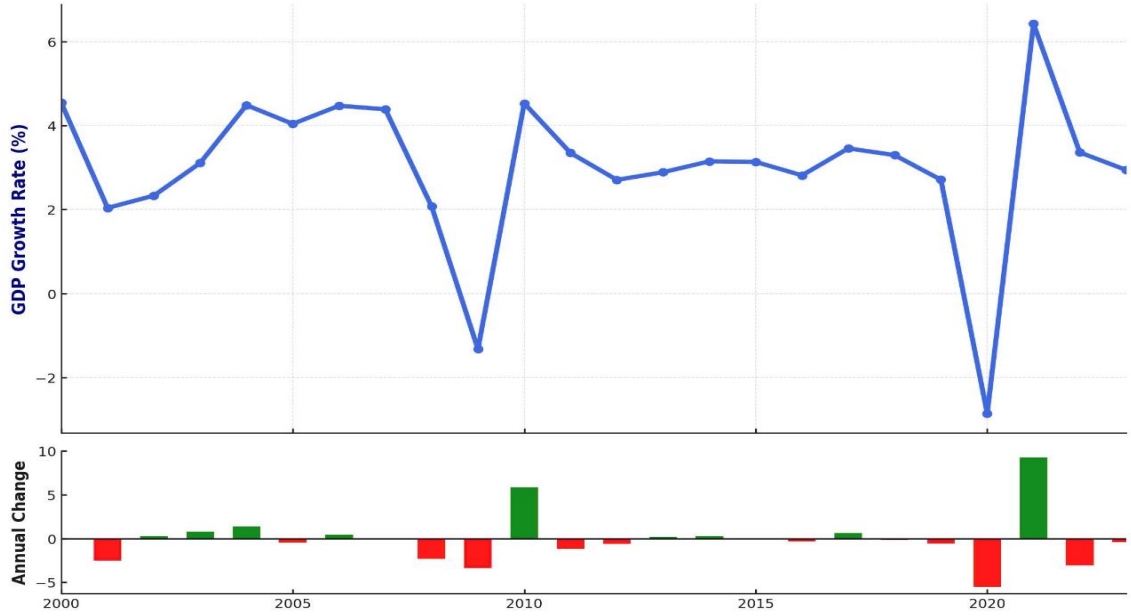
Palavras-chave: *Meio Ambiente Verde. Crescimento Econômico. Desenvolvimento Financeiro. Regressão Quantílica Bayesiana.*

1 INTRODUCTION

Climate change is not only a separate challenge but has also become one of the most urgent global issues. The World Bank together with the United Nations Environment Programme encourages countries to pay more attention to the environment. Therefore, the environment is a major challenge that many countries focus on improving and strengthening with the aim of achieving sustainable economic growth (Stöver, 2016). However, achieving a green environment GE requires the provision of multi dimensional information from a system that ensures transparency in emissions, energy resources, and real savings after accounting for environmental costs. Providing transparent information sources helps countries set sustainable development directions (Kinuthia *et al*., 2025). In other words, countries that actively apply standardized and public environmental reporting systems tend to have more stable institutions due to reduced information costs and improved control efficiency (Zhang and Kamarudin, 2024). A green environment and information transparency are the foundation for sustainable development and help countries achieve long term growth (Appiah *et al*., 2025). Through this, GE does not only stop at providing environmental information but also serves as an important tool in promoting economic development in countries. By reducing the space for corruption and enhancing the accountability of public entities, GE shows its ability to better control resource use and green management, thereby opening new opportunities for economic stability (Ali *et al*., 2023). Especially in the context where environmental degradation increasingly affects the economy (Zheng and Chen, 2024), the strong adoption of transparency solutions leads to deep changes in all aspects of the economy and stability (Diamond and Verrecchia, 1991). A green environment has become an important link in promoting economic growth, contributing to information transparency, and playing a key role in the path toward sustainability.

Figure 1

GDP Growth Trend 2002–2020



Source: Compiled by the authors

Figure 1 shows that overall economic growth tends to decline during the period 2000 to 2023. Two negative GDP points are notable. First, 2009 was the time of the global financial crisis. Second, 2020 was the time when the COVID 19 pandemic broke out. However, environmental issues also stand out, such as the explosion of an oil rig in the Gulf of Mexico in 2010, which caused a major oil spill into the sea. This led to marine pollution and climate change, reducing global GDP to minus 3.34%. Another example is the conflict between Russia and Ukraine in 2022, which damaged the Kakhovka Dam and was considered an ecological disaster due to flooding and the release of toxic substances from sediments. The environment is not only affected by natural disasters or mining activities, but also by war, which is often less emphasized but very serious. Therefore, studying the impact of the green environment on economic growth cannot be ignored. GE, by providing transparent environmental information, helps countries make timely policies, thereby improving and promoting sustainable economic growth. In addition, this study highlights the role of financial development in this relationship. Strong FD helps reduce information costs, making disclosed information more reliable and supporting economic growth (Van *et al*., 2025; Quoc *et al*., 2025a, 2025b). Moreover, a favorable financial environment helps green firms expand their scale, thereby supporting sustainable development (Van & Dinh, 2024). This study provides directions to address

important issues related to the impact of GE on economic growth. The importance of this issue lies in the context of environmental change and its potential to reshape the economic landscape. Based on these arguments, we focus on answering two main questions in this study: how does GE affect GDP, and which policies are suitable to help countries move toward economic growth in the current context.

2 THEORETICAL AND LITERATURE REVIEW

2.1 Theoretical foundation

The theory on the impact of GE on GDP can be approached through the following main theoretical frameworks.

The Environmental Kuznets Curve EKC theory was developed by Grossman and Krueger (1991, 1995) based on the Kuznets curve (Kuznets, 1955). This theory extends to the environmental field and emphasizes an inverted U shaped nonlinear relationship between economic development and social outcomes. In this context, GE improves economic efficiency and promotes technological innovation toward economic growth. In addition, GE discloses transparent environmental information, which helps increase the confidence of international investors and attract foreign investment. At the same time, a green environment helps reduce natural disasters and climate change, creating better conditions for agricultural development and promoting economic growth. FD plays a role in strengthening the transmission of environmental information, opening opportunities for production and business activities, thereby supporting economic growth.

The Porter theory was initiated and developed by Porter and Linde (1995, 1996). This theory emphasizes that strict environmental regulations stimulate innovation and improve long term economic and social efficiency. Within this framework, the environment acts as a driver of innovation, and GE highlights the need for countries to invest in environmental protection, reduce emissions, and improve energy efficiency. This not only helps protect ecosystems but also promotes creativity. As a result, GE helps reduce costs and moves toward sustainable economic growth through green investment. Environmental protection goes hand in hand with economic growth and supports each other in the long run. FD expands innovation capacity and green investment, and FD

supports environmental policies through financial services. In addition, FD helps expand the scale of clean firms, thereby supporting economic growth.

The information disclosure theory was pioneered by Diamond and Verrecchia (1991) based on the information asymmetry theory of George (1970). This theory explains that accurate information disclosure by governments plays an important role in reducing information asymmetry and increasing trust in the economy. In this context, GE provides transparent information on emissions data, energy use, environmental costs, resource management, environmental impacts, and compliance with environmental taxes. In addition, GE reduces opportunities for rent seeking and corruption in public management, enhances accountability and government effectiveness, and helps improve the economy. This shows that GE has a positive relationship with GDP. However, Diamond and Verrecchia note that the effect of this relationship tends to weaken when countries reach a stable level of transparency. FD reduces information costs and helps governments design suitable policies to improve environmental efficiency. Moreover, FD supports small and medium enterprises by increasing access to capital and guiding firms toward clean technologies, thereby supporting economic growth.

2.2 Literature review

From multidimensional perspectives, existing studies clearly show the following findings. Apostu *et al*. (2023) analyzed the relationship between the green environment, economic growth, and the circular economy in European countries, thereby assessing whether current European policies are moving in the right direction toward sustainable development. The research results indicate that gross fixed capital formation and total greenhouse gas emissions contribute to reducing municipal waste, while final energy consumption, GDP, Sox emissions, and Nox emissions increase municipal waste. The novelty of this study lies in the combined analysis of three factors, including the green environment, economic growth, and the circular economy. Based on this approach, the authors propose economic policies to promote the green transition by exploiting the potential of the circular economy. Dzwigol *et al*. (2023) examined the role of the environment, renewable energy, and energy efficiency in green economic growth, with the main objective of reducing greenhouse gas emissions and expanding renewable energy. This study applied the system generalized method of moments GMM, and the

results confirmed a nonlinear U shaped effect of environmental regulations together with the gradual improvement in energy efficiency. These findings can serve as a basis for implementing green economic growth in EU countries and moving toward a non carbon development pathway. Kyriakopoulos (2023) identified the contribution of trails to sustainable development, emphasizing the need for a comprehensive view of land use and land cover that is closely linked to the natural environment. Udeagha and Muchapondwa (2023) aimed to examine the combined effects of the composite risk index CRI, green innovation GINOV, and environmental policy stringency EPS on carbon dioxide emissions CO2 from 1960 to 2020. The regression results show that EPS, GINOV, and RERD contribute to reducing CO2 emissions, while CRI and GDP increase CO2 emissions. This study provides implications for BRICS countries to reduce sectoral risks, create a sustainable environment, and move toward a non carbon economy. Gang Wang *et al*. (2022) investigated the relationship between renewable energy production and sustainable economic growth under the SDGs, highlighting the importance of clean energy systems and strengthening the impact of sustainable energy consumption by using annual panel data and applying the augmented mean group AMG and common correlated effects mean group CCEMG methods. The results show that renewable energy consumption makes a significant contribution to the economy. Ali *et al*. (2023) examined the relationship between renewable energy consumption REC, non renewable energy consumption NREC, carbon dioxide emissions CO2, and economic growth during the period 1975 to 2020. The findings indicate that NREC increases long run carbon emissions, while REC reduces carbon emissions, showing that expanding renewable energy is a feasible strategy to address energy issues, reduce carbon emissions, protect the environment, and promote economic growth in the future. Vineeta Kumari *et al*. (2025) highlighted environmental sustainability as one of the key challenges of the 21st century. This study identifies barriers and challenges that hinder the realization of a truly green environment and concludes by emphasizing integrated development planning, strong governance, inclusive participation, and innovative financial mechanisms to accelerate progress toward environmental sustainability and achieve a sustainable future.

2.3 The role of financial development

In practice, access to and implementation of the green environment differ significantly across countries worldwide, reflecting the uneven level of economic development. One of the core reasons for this difference lies in the level of financial development. The green environment does not depend only on policy commitment but is also closely linked to the financial capacity of an economy to mobilize, allocate, and monitor resources for environmental goals. In countries with a high level of financial development such as Australia, South Korea, and Japan, the financial system is relatively well developed, with a diverse network of financial institutions, developed capital markets, and a high level of transparency. These conditions facilitate access to long term capital at lower costs for green firms and environmentally friendly projects. At the same time, the development of green financial instruments improves capital allocation efficiency, encourages clean technological innovation, and enhances resource use efficiency. As a result, these countries are able to achieve sustainable development goals without reducing economic growth, and may even create new growth drivers through green economic sectors. In contrast, in countries with lower levels of financial development such as Albania, Mali, and Rwanda, financial systems remain limited in scale and depth, making access to capital for green related activities more difficult. In this context, basic financial access for households and firms remains essential for promoting consumption, production, and improvements in social welfare. When financial channels are underdeveloped, green environmental initiatives are often considered secondary to short term economic goals, leading to a limited contribution of the green environment to GDP growth. These differences indicate that financial development is not only a supporting factor but also a key intermediate condition shaping the relationship between the green environment and economic growth. Strong financial development helps reduce information costs, increase transparency, and improve the effectiveness of environmental policy implementation, thereby strengthening the role of the green environment in promoting GDP growth. Based on this reasoning, the study proposes the following hypothesis.

Hypothesis H1: The interaction between financial development and the green environment promotes economic growth.

Based on a review of previous studies, we identify several research gaps as follows.

First, most previous studies assess the green environment using a single indicator such as carbon emissions, renewable energy, or adjusted net savings after accounting for environmental costs ANS. This approach remains limited when studies attempt to construct a composite accounting based index that integrates multiple factors such as emissions, energy resources, ANS, and environmental taxes. More importantly, to date, no study has examined the role of financial development in the relationship between the green environment and GDP, leaving a significant research gap that requires further investigation.

Second, unlike previous studies that mainly rely on traditional frequency based methods, this study applies Bayesian quantile regression to examine the relationship between the green environment while considering the role of financial development across different levels of economic growth. Bayesian quantile regression techniques allow researchers to estimate parameters based on probability distributions, thereby revealing the nonlinear effects of the green environment on GDP and the moderating role of financial development. A notable issue is the strong correlation between the green environment and financial development when assessing their effects on GDP, which often leads to multicollinearity. This explains why previous studies have rarely used financial development as a moderating variable in this context. However, Bayesian quantile regression provides a robust solution to these challenges by addressing endogeneity and multicollinearity issues (Benoit and Van den Poel 2017). This method offers deeper insights into how the green environment affects GDP and examines the moderating role of financial development across economic distributions.

Furthermore, unlike traditional quantile regression QR or panel quantile regression PQR, where statistical information is summarized by a single value such as the mean or percentiles without reflecting estimation uncertainty, Bayesian quantile regression represents each parameter as a probability distribution (Le Quoc Dinh 2024). This allows researchers not only to estimate parameter values but also to describe the uncertainty surrounding these relationships. This feature is particularly important in economic growth modeling, where relevant information may be disrupted by unobservable factors. Bayesian quantile regression is a powerful approach that enables researchers to work with probability distributions by updating estimates over time (Benoit

and Van den Poel 2017). This approach provides more nuanced insights into the impact of the green environment on GDP and the moderating role of financial development, while also delivering more accurate estimates that can support policymakers in designing country specific policies.

Moreover, this study makes several contributions to the existing literature. First, it clarifies the impact of the green environment on GDP and the moderating role of financial development. By applying Bayesian quantile regression, the study offers a multidimensional view of how the green environment affects different segments of the economy and how financial development operates within this relationship. Second, the study provides policy relevant insights on enhancing the green environment, particularly in a context of increasing environmental pressure. At the same time, it highlights the importance of strengthening and improving financial development to enhance its moderating role in promoting the green environment.

3 METHODOLOGY

3.1 Research data

The research data include 65 countries worldwide, selected based on data availability during the period from 2004 to 2020. The data used to measure the variables are compiled from three main sources: (1) World Development Indicators WDI published by the World Bank; (2) data from the Organisation for Economic Co operation and Development OECD; and (3) the International Monetary Fund IMF. In this study, the green environment GE is constructed using the principal component analysis PCA method. The definitions and measurements of all variables are presented in Appendix 1.

3.2 Variable transformation and alignment

Economic growth (GDP) is an appropriate and widely accepted measure to capture the growth level of an economy. It is measured by the percentage change in real GDP between the current year and the previous year, which makes it an indicator reflecting the health of the economy. This variable has been widely used in previous studies, such as Ali *et al*. (2023), Maxwell and Edwin (2023), and Simona *et al*. (2023),

which further confirm its relevance and reliability as a measure in studies on labor market dynamics.

Based on the reviewed literature, the measurement of GE has changed considerably over time. However, there is a common agreement that GE cannot be measured by a single variable. Instead, it is constructed from multiple factors, such as emission related indicators, energy resources, and adjusted net savings after accounting for environmental costs (ANS) (Simona *et al*., 2023; Henryk *et al*., 2023; Maxwell and Edwin, 2023). Compared with previous studies, this research adds an important additional indicator, environmental tax (TAX). This indicator reflects national policies and efforts to internalize environmental costs, thereby improving the completeness of the GE measurement. In this study, GE is constructed from ten component variables: (1) renewable energy consumption (FEC); (2) renewable electricity output (ELC); (3) forest area ratio (FRST); (4) total natural resource rents (TOTL); (5) net deforestation (DFOR); (6) damage from CO2 emissions (DCO2); (7) depletion of energy resources (DNGY); (8) depletion of mineral resources (DMIN); (9) total greenhouse gas emissions (GHG); (10) environmental tax (TAX). These indicators play an important role in building a composite GE index.

To construct the GE index, we apply the PCA technique to the ten component variables in order to condense them into a single composite measure. Table 3 presents the PCA results of the ten component variables and summarizes the main findings. The component variables are reduced into five principal components with eigenvalues greater than 1, explaining 73.24% of the total variance. The eigenvalues and eigenvectors provide detailed information on the contribution of each indicator. If the explained variance of the first principal component exceeds 70%, PC1 is typically used to calculate the composite index. If multiple principal components are retained, the composite index is calculated as a weighted combination of these components, where the explained variance ratios are used as weights (Kurniawan *et al*., 2025). In this study, using only the first principal component (PC1) would lead to a significant loss of information. Therefore, we combine several principal components to construct a single composite index that both preserves most of the explanatory information and provides a more comprehensive measure of GE. The cutoff is determined by selecting components with explained variance cumulatively exceeding 70% and eigenvalues greater than 1.

Table 1

Probability contributions of variables

Dim	Eigenvalue	Proportion	Cumulative
Dim 1	2.75083	0.2751	0.2751
Dim 2	2.46365	0.2464	0.5214
Dim 3	1.09257	0.1093	0.6307
Dim 4	1.01653	0.1017	0.7324
Dim 5	0.87764	0.0878	0.8201

Source: Authors' calculations

From the results in Table 1, we aggregate the retained PCs into a single GE index, using the explained variance ratio as weights. This approach helps preserve most of the information contained in the component variables and has been widely used in previous studies, such as Fernandez and Martos (2020), Zheng and Chen (2024), and Chao and Wu (2017). However, to ensure consistency before aggregation, it is necessary to orient the PCs toward a positive direction (Jain and Mohapatra, 2023). This procedure reflects positive environmental and institutional aspects, where higher PC values indicate higher trust and better institutional quality. Boudt *et al*. (2022) emphasize that reorienting PCs toward an important variable or a positive policy variable makes the composite index easier to interpret while preserving the statistical meaning of PCA. Based on this, the general formula is defined as follows:

$$\mathrm{CI} = \sum_{i=1}^{k} \pi_i Y_i \qquad (1)$$

where:

CI: the composite index.

π_i: the proportion of PC_i.

k: the number of retained principal components.

Y_i: the principal component PC_i.

Based on this framework, the GE score is calculated as follows:

$$GE = 0.2751PC_1 + 0.2464PC_2 + 0.1093PC_3 + 0.\ 0.1017PC_4 \qquad (2)$$

Based on the above arguments, we propose the following hypothesis:

Hypothesis H2: Green environment GE increases GDP.

In addition to the main variables, this study also includes six control variables. These variables play an important role in reducing bias and improving the robustness of the model, including POP, UNE, INF, FDI, UR và TRADE. These variables help strengthen the effect of GE on improving GDP and the role of FD.

3.3 Methodology

Based on previous studies, the baseline research model examining the impact of GE on GDP and the role of FD is specified as follows:

$$GDP_{i,t} = \beta o + \beta_1 GE_{i,t} + \beta_2 FD_{i,t} + \beta_3 GE*FD_{i,t} + \beta_x X_{i,t} + \varepsilon_{i,t} \quad (3)$$

where:

GDP: represents economic growth.

GE: the composite index measuring the green environment.

FD: the index measuring the level of financial development.

GE*FD: the interaction term between GE and FD, reflecting the role of financial development in shaping the green environment.

X: vector of control variables including (POP, INF, UR, UNE, TRADE, FDI).

However, several issues arise in model (1) that need to be addressed in order to reduce estimation bias and ensure model robustness. First, multicollinearity among the explanatory variables may distort the estimates and reduce accuracy. Second, the presence of heteroskedasticity and outliers can affect the stability of the model. Third, endogeneity between the explanatory variables and the error term $\varepsilon_{i,t}$, may lead to serious problems related to the consistency of the estimators.

To address these issues, this study employs the Bayesian quantile regression approach. This method allows researchers to examine the direct impact of GE across different quantiles of economic growth under varying levels of financial development. It provides more reliable estimates, especially when relationships among variables differ across the distribution. By adopting a probability based framework, Bayesian quantile regression incorporates prior information through prior distributions, thereby improving

estimation accuracy and parameter fit. In addition, endogeneity concerns are effectively handled through conditional prior distributions, which enhance reliability and control estimation errors. Therefore, Bayesian quantile regression is a flexible and powerful tool for exploring complex data structures and improving the practical relevance of quantitative analysis (Benoit and Van den Poel 2017).

The baseline model used to analyze the relationship between GE and GDP while assessing the role of FD is specified as:

$$GDP_i = GE_i^T\beta_1 + FD_i^T\beta_2 + GE*FD_i^T\beta_3 + \varepsilon_i \quad (4)$$

In this setting, the regression model can be generalized into a quantile regression framework by minimizing the following loss function for each quantile:

$$\widehat{\beta_\tau} = \underbrace{argmin}_{\beta \in R^k} \sum_{i=1}^{n} \rho_\tau(GDP_i - GE_i^T\beta_1 - FD_i^T\beta_2 - GE*FD_i^T\beta_3) \quad (5)$$

where:

$\rho\tau$ is the check function corresponding to the quantile of interest, measuring the deviation between observed and predicted values at different points of the distribution.

The Bayesian approach incorporates prior distributions into the quantile regression framework, leading to more robust parameter estimation. The likelihood function of the model is given by:

$$f(x|\mu,\sigma,\tau) = \frac{\tau(1-\tau)}{\sigma} exp\left\{-\rho_\tau\left(\frac{x-\mu}{\sigma}\right)\right\} \quad (6)$$

By applying this approach, the study evaluates the impact of GE and the moderating role of FD across different distributions of economic growth. This provides a comprehensive view of how GE affects GDP and highlights the importance of financial development in strengthening or constraining this relationship.

In addition, Bayesian inference updates prior distributions using observed data to obtain posterior distributions, allowing parameter estimation while accounting for uncertainty. The choice of quantiles is crucial in quantile regression, as it affects the

smoothness and accuracy of estimates. Higher quantiles tend to reduce variance but may increase bias, while lower quantiles improve accuracy but raise variance. Therefore, this study employs five quantiles: 0.1, 0.25, 0.5, 0.75, and 0.9. These quantiles enhance the robustness of results while improving the precision of estimated parameters.

By exploiting multiple quantiles, the study provides a richer view of model behavior and the influence of parameters on outcomes. During posterior estimation, the Markov Chain Monte Carlo technique is applied with 15000 iterations. This procedure ensures reliable estimation and offers deeper insights into the impact of GE on GDP and the moderating role of FD in this relationship.

4 RESEARCH RESULTS AND DISCUSSION

4.1 Overview of descriptive statistics

Descriptive statistics of the variables are fully reported in Table 2. The specific results show that GDP has a mean value of 3.07 with a standard deviation of 4.07, indicating substantial variation in GDP within the sample. GDP ranges from a minimum value of −17.82 to a maximum value of 34.36. This suggests that some countries still experience relatively low economic growth, while others achieve very strong GDP performance. This reflects the diversity of the sample, which includes less developed countries, developing countries, and developed countries. The average GE score is 0.24 with a standard deviation of 0.15, reflecting noticeable variation in the data. GE values range from 0, representing countries at an early stage of green environment development, to approximately 1, representing countries that perform well in green environment practices and disclosure. FD has a mean value of 0.43 and a standard deviation of 0.25, indicating relatively complex variation in financial development. The minimum value of 0.06 shows that some countries have a low level of financial development, while the maximum value of 0.99 indicates strong financial development in several countries.

Notably, Table 2 highlights three main issues that need to be considered and clarified. First, there is concern regarding cross sectional dependence, which is an important issue that must be tested before conducting panel data analysis. Ignoring this aspect may lead to biased model results and misleading policy implications. To address this issue, this study applies the Pesaran cross sectional dependence test (Pesaran, 2021).

The results show that all variables are statistically significant at the 1% level ($p < 0.01$), implying the presence of cross sectional dependence. Next, the normality of the data is examined using the Jarque Bera test. The results indicate that all variables do not follow a normal distribution ($p < 0.01$). This suggests that the data exhibit skewness or kurtosis, meaning that the distributions are asymmetric and may contain outliers or heavy tails. Therefore, it is necessary to employ a robust research model to address this issue. Finally, slope heterogeneity is tested. The results show that both the Delta and adjusted Delta statistics (Pesaran and Yamagata, 2008) are statistically significant ($p < 0.01$), emphasizing the presence of slope heterogeneity. Based on these arguments, selecting an appropriate model to address the identified issues is crucial. Conventional models such as OLS, FEM, or SEM may lead to biased results. Therefore, this study employs the Bayesian quantile regression model to capture inference across specific quantiles. Moreover, parameter estimation based on prior distributions is conducted using Bayesian inference, thereby improving the accuracy and reliability of the research findings.

Table 2

Descriptive statistics for variables

Variables	***Mean***	***Std. Dev.***	***Minimum***	***Maximum***	**Pesaran-CD Test**	**Jarque-Bera Test**
GDP	3.0791	4.0705	-17.8212	34.4662	113.66***	142.36***
GE	0.2385	0.1548	0.00000	1.00000	8.6620***	255.78***
FD	0.4370	0.2453	0.0656	0.9968	39.264***	186.46***
UNE	7.2718	4.6092	0.398	29.217	19.856***	283.80***
INF	4.2495	5.4033	-18.8992	84.6834	36.875***	884.82***
UR	64.5840	18.2393	20.757	98.0790	121.09***	43.420***
FDI	6.4418	25.7659	-296.013	431.788	20.015***	0.0000***
TRADE	87.2149	39.8189	22.1059	250.1085	32.682***	76.340***
POP	.9288	.9999	-2.2584	3.1468	11.458***	0.0000***
Slope heterogeneity Test						
Delta		7.396***				
Adj.		11.526***				

*Note: *** indicates the 1% significance level.*
Source: Authors' calculations

4.2 Bayesian quantile regression results

The results of the Bayesian quantile regression (BQR) on the impact of GE on GDP, while examining the moderating role of financial development, for 65 countries over the period 2004–2020 are summarized and presented in Table 3. Within the scope of this study, five quantiles are employed, namely 0.1, 0.25, 0.5, 0.75, and 0.9. These

quantiles play an essential role in improving the accuracy of the results. As emphasized earlier, GE exerts a positive effect on GDP across all quantiles. This finding confirms the significant contribution of GE in the process toward sustainable development. GE functions to increase the level of GDP regardless of the specific quantile considered. However, when investigating the effect of financial development, FD shows a positive influence on GDP across the entire distribution, implying that financial development enhances economic growth. Notably, when considering the moderating role of FD in the relationship between GE and GDP, the evidence indicates that under the role of financial development (GE*FD), the positive impact of GE on GDP is amplified. In other words, the moderating effect of FD is substantial.

Table 3

Bayesian quantile regression results

Variables	Quantile: 0.1			Quantile: 0.25			Quantile: 0.5		
	Estimate	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**
GE	2.94754	0.94205	8.38029	1.81306	-0.38441	3.96827	0.51754	1.591720	2.63473
FD	1.60685	-1.30321	4.24380	0.72369	0.07473	0.90538	1.70211	2.882645	3.47293
GE*FD	4.12412	3.30719	4.65512	2.58692	4.16365	5.43646	3.75208	1.083752	3.28843
FDI	-0.00245	-0.01205	0.00795	-0.00514	-0.01477	0.00637	0.00686	-0.00069	0.01333
POP	1.22803	0.78645	1.61992	0.35792	0.09108	0.62669	0.29989	0.123540	0.48042
UR	0.00579	-0.02490	0.03463	-0.01702	-0.03027	-0.00399	-0.02478	-0.03480	-0.01484
INF	0.07575	0.02266	0.12417	0.08462	0.05105	0.12086	0.11957	0.076871	0.16336
TRADE	0.01485	0.00441	0.02399	0.00845	0.00356	0.01337	0.00561	0.001685	0.00944
UNE	-0.27925	-0.39187	-0.18349	-0.11763	-0.17035	-0.07021	-0.07350	-0.10672	-0.04002
C	-3.7927	-5.9486	-1.4264	2.26971	0.82348	3.78609	4.55064	3.43399	5.62406
Variables	**Quantile: 0.75**			**Quantile: 0.9**					
	Estimate	**Lower**	**Upper**	**Estimate**	**Lower**	**Upper**			
GE	1.44316	1.13783	2.42925	1.3196	7.129969	7.6846			
FD	2.55743	1.96746	3.12378	2.8093	0.493127	4.8861			
GE*FD	2.94538	2.71639	4.96659	3.1649	0.030566	6.8623			
FDI	0.00876	0.00144	0.00019	0.0178	0.000998	0.0340			
POP	0.19120	0.00433	0.00039	0.0610	-0.18284	0.3097			
UR	-0.02685	-0.03786	0.042544	-0.0278	-0.04183	-0.0136			
INF	0.15887	0.11532	0.598624	0.2105	0.159212	0.2628			
TRADE	0.00859	0.00439	0.035954	0.0117	0.005924	0.0174			
UNE	-0.03892	-0.07710	0.00162	-0.0154	-0.06732	0.0430			
C	5.88508	4.68436	0.000075	6.8152	5.287059	8.3042			

Source: Authors' calculations

4.3 Discussion

The research results presented in Table 3 indicate the impact relationship between GE and GDP across 65 countries worldwide under different quantile contexts. By using five quantile values (0.1, 0.25, 0.5, 0.75, and 0.9), the study provides a comprehensive view of the impact of GE across different segments of economic growth. The results show that GE and GDP have a clear, consistent, and positive relationship, with GE affecting GDP across all quantiles. This implies that GE plays an important role in enhancing economic growth globally, regardless of the specific quantile, GE always increases GDP, highlighting its importance for each country. The consistent effect across the entire growth distribution indicates the positive impact of GE, especially through the disclosure of information related to emissions, energy resources, adjusted net savings after accounting for environmental costs, and environmental taxes in a transparent manner. In addition, this contributes to reducing the scope for corruption among environmental control agencies and increasing accountability in environmental governance. As a result, economic growth is improved and enhanced, moving toward sustainable development. This finding extends and strengthens the existing literature on GE, particularly when compared with previous studies such as Ali and *et al*. (2023), Maxwell and Edwin (2023), and Simona and *et al*. (2023), which examined the impact of environmental factors on economic growth. Earlier studies mainly approached the issue by establishing a general relationship between the environment and economic growth. This study focuses on the aspect of transparent disclosure of environmental management information, providing deeper insights into how GE addresses economic growth by reducing corruption and improving the efficiency and stability of national governance systems. The study shifts the focus toward GE as transparent and accurate disclosure of environmental information, offering a more comprehensive and updated perspective on the role of verified environmental information in strengthening economic systems. Especially in the current context, environmental quality and environmental information are receiving increasing attention across countries. These results strongly support hypothesis H1 that GE has a positive impact on GDP. Moreover, the findings are consistent with established theories, including the Environmental Kuznets Curve theory EKC (Grossman and Krueger, 1995), the Porter hypothesis (Porter and Linde, 1991, 1995), and disclosure theory (Diamond and Verrecchia, 1991). These theoretical frameworks suggest that transparent disclosure

of environmental indicators increases trust in institutions and reduces corruption by public agencies that may misreport information for personal gain. Accordingly, GE not only provides accurate information on the environment, emissions, energy, and adjusted net savings after accounting for environmental costs, but also enhances accountability through stricter environmental regulations, especially in the current context where countries increasingly emphasize transparency of environmental information to achieve sustainable development.

Regarding FD, the results show that FD has a positive impact on GDP across all considered quantiles. This indicates the consistent role of financial development in promoting economic growth, regardless of whether the economy is at a low, medium, or high growth level. From an economic perspective, financial development improves the efficiency of capital allocation, expands access to credit, and supports investment activities, thereby creating favorable conditions for stable GDP growth. More importantly, the estimated results of the interaction term GE FD are positive and statistically significant across all quantiles, indicating that FD plays a moderating role and amplifies the positive impact of GE on economic growth across the entire GDP distribution. This implies that at all levels of economic growth, from low to high, the development of the financial system enhances the ability to translate green environment efforts into concrete economic growth outcomes. FD facilitates easier access to finance for green projects and initiatives, reduces financial costs, and encourages innovation in environmentally friendly technologies. As a result, the positive impact of GE on GDP is not limited to a specific group of countries or a particular growth level, but is uniformly amplified across all quantiles. These findings emphasize that FD is a key factor linking environmental objectives with economic growth goals, thereby strengthening the path toward sustainable development for the countries in the research sample.

5 CONCLUSION

This study aims to evaluate the impact of GE on GDP and the moderating role of FD across 65 countries worldwide from 2004 to 2020. Using the Bayesian quantile regression method, we find that GE consistently increases economic growth across all quantiles, including 0.1, 0.25, 0.5, 0.75, and 0.9. In addition, the study finds that FD

strengthens the relationship between GE and GDP. Specifically, FD amplifies this relationship at all quantiles.

These findings expand a multidimensional view of how GE contributes to higher GDP and highlight the important role of FD, with continuous positive effects across different growth segments and the enhancing capacity of FD. This emphasizes the importance of GE and the moderating role of FD in increasing global GDP, while underscoring the need to improve transparency in the economic context through accurate disclosure of environmental information, promoting government effectiveness and reducing the scope for corruption. The study provides valuable insights into how GE affects economic growth and the essential role of FD. It also highlights the importance of implementing policies to maximize the benefits of GE and improve the financial system.

These findings contribute to the ongoing debate on environmental issues regarding how GE, through transparent information disclosure, can be integrated into the economic growth framework toward sustainable development, while accounting for the moderating effect of FD. By addressing the research questions, the study not only deepens the understanding of how GE affects GDP and the role of FD in this relationship, but also expands empirical evidence that transparent information disclosure helps improve the global economic environment. The results provide useful information for policymakers to design policies aimed at increasing GDP and promoting sustainable economic growth.

Based on these findings, we recommend that countries focus on improving transparency and providing accurate and comprehensive environmental information to enhance stability and reduce corruption. In particular, in countries with strong growth levels, there should be a shift from expanding GE to refining it. This means that countries with high GDP levels can shift their focus from developing new regulatory frameworks to improving implementation capacity and strengthening the quality of green policy monitoring. In addition, applying AI technologies to information disclosure can reduce marginal costs and information bias. In such cases, expanding and improving GE is a more effective strategy for addressing economic growth challenges and promoting sustainable development.

Furthermore, countries should also expand their financial systems by implementing appropriate financial policies and instruments aimed at greening and sustainable development, thereby supporting broader economic growth. However, an important point to note is that no single policy is suitable for all countries or for all stages

of development. Instead, the design of appropriate policies should be based on a deep understanding of how GE affects GDP. By adopting flexible and targeted policies, countries can create opportunities for development and international integration.

One limitation of this study is that the construction of the GE index could be expanded by incorporating additional relevant variables, such as stricter environmental indicators, to better assess the effectiveness of environmental policies. In future research, the authors plan to evaluate GE over a broader scope or apply alternative approaches, with the aim of proposing policies that are more suitable to the current context.

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APPENDIX

Appendix 1

Variable Description and Data Sources

Code	Variable	Measurement	Source
Dependent variable			
GDP	Economic growth	GDP per capita growth (%).	WDI
Independent variables			
GE	Green environment	In this study, GE is measured using the principal component analysis PCA technique. All component variables are standardized prior to conducting PCA.	Authors
1. FEC	Renewable energy	Share of renewable energy in total final energy consumption (%).	WDI
2. ELC	Renewable electricity	Share of renewable electricity in total electricity production (%).	WDI
3. FRST	Forest area	Forest area as a share of total land area (%).	WDI
4. TOTL	Total natural resource rents	Total natural resource rents (% of GDP).	WDI
5. DCO2	CO_2 damage	Monetary value of damage caused by CO_2 emissions (% of GNI).	WDI
6. DFOR	Net forest depletion	Monetary value of forest resource depletion due to deforestation (% of GNI).	WDI
7. DNGY	Energy depletion	Monetary value of excessive extraction of energy resources including oil, natural gas, and coal (% of GNI).	WDI
8. DMIN	Mineral depletion	Monetary value of mineral extraction (% of GNI).	WDI
9. GHG	Greenhouse gas emissions	Total greenhouse gas emissions (Mt CO_2e), including CO_2, CH_4, N_2O, and F gases, divided by total population to obtain per capita values.	WDI
10. TAX	Environmental taxes	Environmental tax revenue as a share of GDP (%).	OECD
Moderating variable			
FD	Financial development index	This study uses 105 indicators from GFDD and 46 from Finstats. Experts have built the indexes (FID, FIA, FIE, FMD, FMA, FME, FI, FM) and combined them into the overall FD index.	IMF
Control variables			
TRADE	Trade openness	Total exports and imports as a share of GDP (%).	WB
UR	Urban population	Urban population percent of total population.	WB
FDI	Foreign direct investment	Foreign direct investment, net inflows percent of GDP.	WB
POP	Population growth rate	Annual population growth (%)	WB
INF	Inflation rate	Percent change of CPI each year.	WB
UNE	Unemployment rate	In this study unemployment is measured based on the Unemployment indicator, total percent of the total labor force. It shows the percent of the labor force that is unemployed and actively looking for work.	WB

Authors' Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study's findings are fully available within the article.

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